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MODERN PRACTICE IN THE REMOVAL OF TASTE AND ODOR[1]

By Norman J. Howard[2]

Of recent years, in the sanitary world, the question of taste and odor in public water supplies has received universal attention. The prevention of taste is of considerable importance, and each year sees further advances made not only in the study of removal, but of taste prevention. It would seem that the solution to such problems would largely depend upon active laboratory work. Practical observation, chemical experiment and microscopical examination should, and frequently actually do indicate causes. With these established, and seasonal or periodic incidence recorded, prevention should be possible. The margin between taste and odor is small and often complaints of taste are made when only slight odors exist. Where complaints are justified, publicity as to the real cause of taste will often do much to satisfy consumers, who usually are more concerned with the safety of the supply than with objectionable taste. The description of taste and odor presents difficulties, on account of their extensive nature. The purpose of this paper is to deal with the commoner conditions found in practice and to discuss briefly methods of elimination and prevention. At the outset it should be stated that laboratory research has frequently demonstrated that certain tastes cannot be removed immediately, but, that once their cause has been established, elimination speedily follows.

At the present time, problems involving taste are largely confined to excessive algae growths and to the formation of chemical compounds following the sterilization of water with chlorine. The presence of iron and gases may also give rise to complaints. The discharge of various industrial wastes into rivers and streams, from which water supplies are drawn, is the cause of many difficult problems that engineers and sanitarians must solve. It is proposed to deal in this paper with taste and odor removal by aeration, filtration and chemical processes. Time does not permit elaboration on the methods of aeration and filtration in general practice, since it is assumed that aeration means the rapid exposure of water to air with a subsequent oxidation of the organic matter and the removal of excessive carbonic acid and certain odor producing gases. In general, where filtration is employed, aeration should follow the filtration process. Where odors result from gas production, or when iron in solution is present, aeration prior to filtration is preferable.

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Water containing iron in excess of two parts per million will give a taste described as inky, while water containing iron and sulphuretted hydrogen give a particularly offensive odor, although the gas may be readily removed by aeration. The cause of sulphuretted hydrogen in water, particularly in well supplies, may usually be demonstrated by a topographical survey. Such waters may be exceptionally pure, and, if the gas formation is not produced by the reduction of sulphates, then some inorganic reducing agent may be the cause. In waters containing calcic sulphate and organic matter, a calcic sulphide is formed, even at ordinary temperatures, by the action of the organic matter on the sulphate. The sulphide is decomposed by the carbonic acid and sulphuretted hydrogen is liberated, which imparts to the water an unpleasant taste. Waters containing iron and gases invariably contain carbonic acid in large quantities. When iron is in solution, as a ferrous carbonate or sulphate, aeration produces precipitation, the iron coming down in an oxidized state. If iron is present in large quantities, it may be necessary to aerate the water or introduce air under pressure, and subsequently to apply lime or alum. The resultant precipitate would have to be settled out before filtration. Calcium hypochlorite has been successfully used in the removal of odors and iron, and has been shown to possess remarkable powers of oxidizing organic compounds. The whole question of nuisance arising from the presence of gases and iron in solution may usually be solved by aeration and filtration processes.

TASTE FROM MICROSCOPIC-ORGANISMS

Taste and odor from the presence or decomposition of microscopic organisms are world-wide. Seasonal variation in the developments of algae is more or less controlled by climatic conditions. For the purposes of this paper the subject may be divided into two groupings, bacteria and algae. The direct relation of bacteria to taste, with the exception of crenothrix, is not apparent. Bacterial decomposition causing taste and odor has followed the discharge of sewage and other wastes into rivers and streams deficient in oxygen. The effluents from creameries are particularly offensive, forming fungoid growths which rapidly decompose and produce foul conditions. In slow flowing streams the discharge of putrescible matter is objectionable and may cause highly offensive tastes and odors. As these invariably occur during warm weather and frequently are only of short duration, the installation of aeration plants is hardly justified, and filtration alone will do much to remove the objection. Chlorine treatment will also materially assist, by preventing the putrefying conditions. Ordinarily, taste does not result from crenothrix, but this organism in the presence of iron, with which it is always associated, may produce a characteristic taste. There are cases on record where decomposition of crenothrix has imparted a distinct taste. Here again, aeration followed by filtration is effective. Filtration alone has proved beneficial not only in removing the organisms, but in reducing the iron content. Laboratory experiments, conducted at Superior, Wis., some few years ago, where the water prior to treatments was highly colored, and contained crenothrix in large numbers, demonstrated the fact that crenothrix was completely removed by the filters without aeration, but that heavy deposits on the surface of the filters caused considerable trouble by shortening the filter runs.

Complaints of taste and odor arising from excessive algae growths are frequently encountered. They are, however, somewhat easier to overcome on account of the definite cause being known. Their removal requires much skill and careful supervision. Treatment of such waters usually involves a pre-chemical application of copper sulphate or other reagents, followed by aeration or filtration. The writer feels that water conditions vary enormously and the amount of chemical found sufficient in one case may prove totally inadequate in another. In other words, the application should be based not only upon the microscopic content, but upon the physical and chemical nature of the water. The definite establishment of free and half-bound carbonic acid and of the organic matter present is of great importance, decomposition and solubility of copper sulphate being dependent upon these conditions. The number of algae causing trouble is so great and well known, that it is needless to dwell upon this subject. It is assumed that taste and odor do and will develop in all cases, when specific organisms are present in sufficient numbers. During the past few years, great advances have been made in the elimination of complaints arising from excessive algae growths. The brilliant research work of Sir A. C. Houston on the London water supply has suggested radical changes of importance. He was able to demonstrate in England that "in certain cases objectionable taste in waters resulting from algae growths could be removed by the addition of minute doses of permanganate of potassium. The dose varies with the oxidisability of the particular water involved, but in dealing with the London supply, the innocuous dose of about 2.5 to 5 pounds of permanganate per million gallons of water was found to destroy the taste in a few minutes. The faint preliminary pink tinge imparted by the addition of the permanganate rapidly faded away, and, in practice, the consumer received a tasteless water with no pink tint, but slightly browner in color than normal."

He points out that such treatment is only admissable in special circumstances. Houston's further researches demonstrate that excess chlorine or permanganate was able to remove certain tastes which frequently followed the application of chlorine for sterilization purposes. When working on the New York supply recently Brush and Hale were able to show that copper sulphate was successful in killing large numbers of organisms including tabellaria, asterionella and synura. Chlorine was applied and caused a reduction in the number of organisms, though not to the same extent as copper sulphate. The most interesting feature of their work was the fact that, in one case where tabellaria was found, it was shown that the numbers present were insufficient to cause taste, yet, after chlorine was applied, objectionable taste followed. In the taste resulting from synura, the application of chlorine was increased from 0.3 up to 0.73 part per million. A sample taken 1500 feet down the stream from the point of chlorine application and tested fifteen minutes after addition, showed the synura taste to be reduced and a combination of synura and chlorine taste to be present. Samples collected about eight hours later, showed a slight chlorine taste, but the cucumber taste from the synura had disappeared. Brush states "Whether the excess chlorine oxidizes the synura oil, or forms a tasteless compound is not known, but whatever may be the chemical reaction, the important factor for water-works operators is the removal of taste." Later he adds: "The increase in copper sulphate apparently more promptly and completely destroys the organisms, and thus fully exposes its oils to mechanical removal in the flow through the aqueducts and to the later chemical reaction with the chlorine at Kensico. The increase in the chlorine does destroy to some extent the organisms, but its more important action appears to be a rapid neutralization of the synura oil through a chemical process." The work of Brush and Hale has demonstrated on a large scale the practicability of removing taste and odor by treatment with copper sulphate and excess chlorine. Their findings may be of great value in solving future problems of a similar nature.

Some interesting observations were made by Hannan in the laboratories at Toronto, to determine if algae were sensitive to differences in alkalinity, as well as to hydrogen-ion concentration. It was noted that in a water containing a luxuriant growth of algae (chlorophyceae) which was treated with normal acids: (1) enough to nearly neutralize the alkalinity, (2) equivalent to about one-third the alkalinity, marked changes occurred. In the nearly neutralized water in warm weather, growths stopped in less than three days, and died off, whilst in the partly neutralized sample the organism thrived. Possibly the alkalinity acts as a carrier of carbonic acid between the atmosphere, etc., and the algae. When the algae are flourishing, the hydroxyl-ions will generally be found to be high, and, as it is lowered, a point occurs where they may die off rapidly. It should be mentioned that Houston found that, in waters containing fragellaria and asterionella the addition of acid produced no ill effects upon the organisms. He states: "In some experiments the dissolved carbonic acid in the water was first neutralized, in others it was increased by the addition of traces of acid, but in neither case was any constant or appreciable difference in results observed from those just described." The explanation of these two conditions is somewhat problematical, and it may be that there is a definite range for the development of each type of organism. It is well known that different quantities of copper sulphate are required to treat different organisms and it is possible that different hydrogen-ion concentrations may also play an important part in the development and death points of these lower forms of vegetable life. This is a matter which should be demonstrated on a practical scale where opportunity occurs. If it were found that hydrogen-ion concentration controls the situation, the treatment would be simple.

TASTE AND ODOR FOLLOWING CHLORINATION OF WATER

The greatest objection raised against the chlorination of water has been the production of taste and odor in certain supplies. This condition has at times been used as an argument against the installation of sterilizing plants, and it must be admitted that, where these objectionable conditions periodically occur, they constitute a real nuisance. In many cases taste could be overcome if authorities would make a thorough investigation definitely to establish a cause. The City of Toronto has just authorized a year's research work on this important subject, and the preliminary observations carried out are most encouraging. The cause of taste following the chlorination of water is not definitely established. Yet the removal of the cause of certain controlling conditions, observed at Milwaukee and elsewhere, has resulted in the elimination of taste. In treated waters two types of taste occur, a chlorine and a medicinal taste. The latter is sometimes described as resembling iodoform. Each taste generally occurs separately. The writer has no record where chlorine and iodoform taste have been reported present at the same time. Often excess chlorine smells and does not taste, but the iodoform compound both tastes and smells, particularly when the water temperature is above 50°F. The cause of the chlorinous taste is, as the word implies, due to excess chlorine, while the cause of the iodoform taste is said to be due to the presence of chloro-phenols. Extensive observations made by the writer have not convinced him that this is the sole cause, although it must be admitted that phenol in small quantities does combine apparently with chlorine to form chemical compounds which produce offensive tastes and odors. Laboratory work carried out during the past few months has produced some surprising and at times puzzling results. It has been assumed generally that the presence of organic matter was essential for the production of iodoform taste in chlorinated water. In distilled water treated with taste-producing doses of chlorine and phenol, the characteristic iodoform taste is not produced, but a pronounced chlorinous taste results. If this same water is passed through a rapid sand filter, the organic matter or some unknown substance taken up by the water produces most offensive taste and odor. Inversely, slow sand filtered water after treatment with chlorine and phenol develops a taste which is greatly lessened, however, by its passage through the same filter. When in Europe last summer, records were shown to the writer indicating that the presence of organic matter and phenol was not necessary for the production of the iodoform taste. A deep well water of great purity and free from phenols had received some slight surface water pollution and consequently was chlorinated. The well formed part of a supply for a large community and, after treatment with a small dose of chlorine, a pronounced iodoform taste resulted. One is forced, therefore, to the opinion that, while organic matter and phenols contribute to taste production, in certain cases there must be other causes which act in a similar taste-producing manner. In support of this, it should be pointed out that, at Toronto, where industrial wastes are discharged into the city sewers all the year round, and extensive tests are daily made on the raw water, the iodoform taste occurs largely in the early spring and late fall. If phenol were the only cause of this taste, objectional conditions would prevail throughout the year. The obvious answer is that, at certain low temperature periods, some other organic or vegetable matter combines with chlorine or phenol or both and these compounds produce the conditions complained of. It is also possible that, if phenol is the direct cause, increased biological activity in the warm summer months assists in preventing the formation of obnoxious chemical compounds. Before discussing the iodoform taste in detail, it would be well to dwell briefly upon the chlorinous taste or odor, which not infrequently occurs under two conditions: first, in water comparatively free from pollution, and, second, in water where too great a quantity of chlorine has been applied. The elimination of the first named condition is practically impossible, except by aeration which is neither practical nor necessary. Water containing a small excess of chlorine, particularly when the temperature is low, has a slight odor when first drawn from the tap, but this rapidly disappears upon exposure to the air. In waters containing chlorine in excess of the amount necessary for sterilization purposes, both taste and odor exist. Tea made from such water will have a most objectionable taste due to the action of the chlorine on the extractive matter present. As is the case when phenol is present, it is possible that some similar compound is formed by the combination of chlorine and tannin. The chlorine absorption method, as suggested by Wolman and Enslow, is very practical. As several observers have reported the elimination of taste since using this system, it would seem well worthy of adoption. In Toronto, the establishment of color standards was found to reduce greatly the chlorinous taste. The dosage necessary for sterilization purposes was worked out, and the blue color produced by definite doses of chlorine, in the presence of starch and iodide, was matched artificially. By making up color standards numbered 1 to 5, and establishing the fact that colors 3 to 5 were sufficient to sterilize the water under varying conditions, chlorine operators were instructed to keep their dosage within these color ranges. This is not put forward as a solution for taste elimination. Since its adoption in Toronto, however, the number of complaints has been greatly lessened. The colors do not represent any definite quantity of applied chlorine, but generally speaking colors 3 to 5 represent approximately an application of 0.175 to 0.225 parts per million of chlorine with a water temperature ranging between 33° and 45°F. As the water warms chlorine is absorbed more rapidly and with a temperature of 68°F., it may be necessary to apply 0.375 parts of chlorine to maintain a color of 3 to 4. The organic content and temperature of the water will be found to control practically the rate of chlorine absorption. The formula for preparing the color standards is as follows.

STANDARD NUMBER	DISTILLED WATER	0.01 PER CENT BRILLIANT MILL GREEN. S.	0.01 PER CENT CARDINAL RED. J.
	cc.	cc.	cc.
1	150	4	0.866
2	150	5	1.053
3	150	6	1.10
4	150	7	1.15
5	150	8	1.25

The standards should be made up weekly, placed in China cups and protected from the light. In all taste producing conditions there must be controlling factors and often it is difficult to avoid taste without taking chances on the final quality of treated water, particularly where it is unfiltered.

By far the most serious taste to overcome is the iodoform one, because, when the taste has once developed, its elimination is difficult. In general, water which tastes after treatment with chlorine improves on storage, but, when the iodoform taste is present, it steadily deteriorates, and should it warm up, a chemical odor can be detected. In connection with the production of this taste, Houston's remarks as recorded in his Fifteenth Annual Report are of considerable interest. He states:

> His experience has indicated that the iodoform taste can practically always be removed or prevented, either by increasing the dose of chlorine sufficiently, or by adding potassium permanganates as well as chlorine to the water. In the former event, the excess of chlorine may have to be removed by dechlorination (solution of sulphurous acid gas, sodium sulphite, bisulphite, or thiosulphate) and in the latter case it is desirable to remove the precipitate of manganese oxide. The permanganate can be used before, at the same time as, or after the addition of chlorine, that is, it can be used either to prevent the occurrence of the iodoform taste, or to remove it after it has already developed. Similarly, the whole of the super-dose of chlorine may be added to the water at one time, or more chlorine may be added to overcome an iodoform taste, which has already occurred in a chlorinated water. Enormous doses of chlorine (one in 11,000) may be added to water and the taste of chlorine entirely removed by the use of a suitable anti-chlor (de-chlorination). When, however, the chlorinated water has developed the iodoform taste, de-chlorination is powerless to remove it.

One of the most important observations made was that, when dealing with filtered water, chlorine or permanganate could be used before, or after filtration, or chlorine added before and the permanganate after filtration, but the addition of permanganate before and chlorine after invariably produced an iodoform taste. The experiments as conducted by Houston usually involved several hours contact. In this country, this condition is difficult to attain since the water often passes into use almost immediately after treatment. This, of course, does not apply to cities where the supply comes from impounding reservoirs or where the works are located outside the city limits. The cause of the iodoform taste has been the subject of extensive research. The officials of the City of Milwaukee are credited with being the first to demonstrate the relationship of phenols and chlorine to the production of taste. During the past few years in Toronto, extensive investigations have been made upon taste-producing conditions. Numerous hypotheses have been advanced from time to time and have included the microscopic content, the biological content, the formation of chloramines and latterly the formation of chloro-phenolic compounds. The relation between microscopic and biological content and iodoform taste has not been demonstrated, although, when taste does develop, there is often a pronounced increase in both conditions in the raw water. Similarly, abnormally high free ammonia has periodically occurred at these times and the formation of chloramines has been suggested. This latter compound of ammonia and chlorine actually produces an objectionable taste and smell when occurring under pollution conditions. Curiously enough, when chloramine is used as a sterilizing reagent, no taste occurs.

Daily tests have recently been made in Toronto to determine the phenolic content of the raw and filtered water. Results have shown that when the water was polluted with sewage containing industrial wastes, phenol was present in quantities up to 0.012 p.p.m., the average figure in March and April being 0.00173 and 0.0021 p.p.m. in two intakes respectively. The first named figure was reduced by slow sand filtration to 0.00083 part and the latter figure to 0.0011 by the drifting sand plant, an approximate reduction of 50 per cent. The slow sand system gives a slightly higher removal. Iodoform taste occurred in the city water with a residual phenol content of 0.006 p.p.m. when only 0.2 part of chlorine was applied. This actual condition confirmed the laboratory experiments described later in this paper. Generally speaking, laboratory tests, when using a small rapid sand filter, have shown a remarkable decrease in taste with and without the application of aluminum sulphate.

Owing to the uncertainty as to the controlling factors in iodoform taste, one is compelled to deal with established conditions, which at present time are limited to phenol. The estimation of phenol when present in small quantities is difficult, methods at present in use giving unreliable results. The system as devised by Trowbridge at Newcastle, Pa., would appear to be the best in use, but the writer has not always been able to completely recover amounts of applied phenol when using his method, or to secure satisfactory blanks. When working in the Toronto laboratories, using Lake Ontario water, we have been able to establish the definite dosage of chlorine and phenol which combines and forms the iodoform taste. The chief point established is that the critical figure which causes taste is close to the actual dose of chlorine applied in many cities, thus explaining why taste so often occurs. The following table gives the quantities of phenols and chlorine applied, and the taste and odor condition which resulted.

The tables presented above are longer than originally intended, but it is felt that their publication will indicate better the taste range and possibly be of assistance in finding a solution to the problem in general. It should be clearly understood that these results

Taste conditions when using Lake Ontario slow sand filtered water with varying doses of chlorine and phenol

0.017 p.p.m. of phenol

Cl, p.p.m.	0.091	0.182	0.273	0.364	0.455	0.546	0.637	0.728	0.819	0.910	1.37	1.82
Taste—45 min.	tr. I	s. I	I	tr. I	I	Cl	Cl	Cl	s. Cl	s. Cl	s. Cl	s. Cl
18 hrs.	tr. I	s. I	s. I	tr. I	I	tr. Cl	tr. Cl	tr. Cl	s. Cl	s. Cl	s. Cl	s. Cl
Odor —45 min.	tr. I	s. I	s. I	?	Cl	Cl	Cl	Cl	s. Cl	s. Cl	s. Cl	s. Cl
18 hrs.												

0.015 p.p.m. of phenol

Cl, p.p.m.	0.090	0.135	0.181	0.226	0.271	0.316	0.362	0.452	0.543	0.633	0.724	0.905
Taste—45 min.	none	tr. I	s. I	s. I	I	I	s. I	s. I	none	?	?	Cl
18 hrs.	none	tr. I	I	I	I	I	I	tr. I	none	tr. Cl	Cl	s. Cl
Odor —45 min.	none	none	I	?	I	I	I	I	none	tr. Cl	Cl	s. Cl
18 hrs.	none	tr. I	I	I	s. I	I	I	none	none	tr. Cl	Cl	s. Cl

0.013 p.p.m. phenol

Cl, p.p.m.	0.089	0.133	0.177	0.221	0.266	0.310	0.354	0.443	0.531	0.619	0.708	0.886
Taste—45 min.	none	tr. I	tr. I	I	s. I	s. I	s. I	I	tr. Cl	Cl	Cl	s. Cl
18 hrs.	none	none	tr. I	I	I	tr. I	tr. I	?	none	none	Cl	s. Cl
Odor —45 min.	none	none	tr. I	tr. I	I	I	tr. I	tr. I	Cl	Cl	Cl	s. Cl
18 hrs.	none	none	none	I	I	tr. I	none	none	none	none	?	Cl

0.010 p.p.m. of phenol

Cl, p.p.m.	0.078	0.118	0.157	0.196	0.235	0.274	0.313	0.392	0.470	0.548	0.626	0.783
Taste—45 min.	none	?	tr. I	tr. I	tr. I	none	none	tr. Cl	tr. Cl	tr. Cl	tr. Cl	Cl
18 hrs.	none	?	tr. I	I	s. I	s. I	tr. I	none	none	none	?	?
Odor —45 min.	none	none	none	tr. I	tr. I	none	none	tr. Cl	Cl	Cl	Cl	s. Cl
18 hrs.	none	none	none	I	I	tr. I	none	none	none	none	?	Cl

0.009 p.p.m. of phenol

Cl, p.p.m.	0.104	0.156	0.208	0.260	0.312	0.364	0.416	0.520	0.624	0.728	0.832	1.04
Taste—45 min.	none	none	tr. I	I	s. I	I	?	Cl	Cl	Cl	Cl	Cl
18 hrs.	none	?	?	tr. I	s. I	tr. I	none	none	tr. Cl	Cl	Cl	Cl
Odor —45 min.	none	none	none	none	I	I	Cl	Cl	Cl	Cl	Cl	Cl
18 hrs.	none	none	none	tr. I	I	tr. I	none	none	tr. Cl	Cl	Cl	Cl

0.007 p.p.m. of phenol

Cl, p.p.m.	0.104	0.156	0.208	0.260	0.312	0.364	0.416	0.520	0.624	0.728	0.832	1.04
Taste—45 min.	none	?	tr. I	tr. I	s. I	?	?	?	Cl	Cl	s. Cl	s. Cl
18 hrs.	none	none	tr. I	tr. I	tr. I	?	none	none	s. Cl	s. Cl	s. Cl	s. Cl
Odor —45 min.	none	?	?	?	L	tr. I	tr. Cl	tr. Cl	Cl	Cl	s. Cl	s. Cl
18 hrs.	none	none	tr. I	tr. I	I	?	none	none	s. Cl	s. Cl	s. Cl	s. Cl

0.005 p.p.m. of phenol

Cl, p.p.m.	0.092	0.138	0.184	0.230	0.276	0.322	0.368	0.460	0.552	0.664	0.737	0.920
Taste—45 min.	none	none	tr. I	tr. I	s. I	Cl	Cl	Cl	Cl	s. Cl	s. Cl	s. Cl
18 hrs.	none	none	?	?	I	tr. I	?	Cl	Cl	Cl	s. Cl	s. Cl
Odor —45 min.	none	none	?	tr. I	I	Cl	Cl	Cl	Cl	Cl	s. Cl	s. Cl
18 hrs.	none	none	none	none	tr. I	tr. I	?	Cl	s. Cl	s. Cl	s. Cl	s. Cl

0.002 p.p.m. of phenol

Cl, p.p.m.	0.100	0.150	0.201	0.251	0.301	0.351	0.402	0.503	0.603	0.703	0.804	1.01
Taste—45 min.	none	?	I	s. I	tr. I	?	tr. Cl	Cl	Cl	Cl	Cl	Cl
18 hrs.	none	?	tr. I	I	tr. I	?	none	none	none	?	tr. Cl	Cl
Odor —45 min.	none	?	tr. I	tr. I	tr. I	Cl	Cl	Cl	Cl	Cl	Cl	Cl
18 hrs.	none	?	?	?	none	none	none	none	none	none	?	Cl

Taste conditions when using Lake Ontario slow sand filtered water with varying doses of chlorine and phenol—continued

0.0002 p.p.m. of phenol

Cl, p.p.m.	0.099	0.149	0.198	0.248	0.297	0.347	0.396	0.495	0.594	0.693	0.792	0.890
Taste—45 min.	none	none	none	none	none	none	?	tr. Cl	Cl	Cl	Cl	Cl
18 hrs.	none	none	none	none	none	none	none	none	?	?	?	Cl
Odor —45 min.	none	none	none	none	?	?	?	tr. Cl	Cl	Cl	s. Cl	Cl
18 hrs.	none	none	none	none	none	none	none	none	none	none	tr. Cl	Cl

Taste conditions when using Lake Ontario slow sand filtered water with low doses of chlorine and varying doses of phenol

0.050 p.p.m. of chlorine

Phenol, p.p.m.	0.002	0.004	0.005	0.007	0.009	0.010
Taste—45 min.	none	none	none	none	none	none
18 hrs.	none	none	none	none	none	none
Odor —45 min.	none	none	none	none	none	none
18 hrs.	none	none	none	none	none	none

0.075 p.p.m. of chlorine

Phenol, p.p.m.	0.002	0.004	0.005	0.007	0.009	0.010
Taste—45 min.	none	none	none	none	none	none
18 hrs.	none	none	none	none	none	none
Odor —45 min.	none	none	none	none	none	none
18 hrs.	none	none	none	none	none	none

0.190 p.p.m. of chlorine

Phenol, p.p.m.	0.002	0.004	0.005	0.007	0.009	0.010	0.012	0.014	0.016	0.017
Taste—45 min.	none	none	?	?	tr. I	tr. I	tr. I	L	I	s. I
18 hrs.	none	?	tr. I	tr. I	I	s. I	s. I	s. I	s. I	s. I

0.205 p.p.m. of chlorine

Phenol, p.p.m.	0.004	0.010	0.017	0.023	0.028	0.033	0.038	0.043	0.049	0.054	0.059	0.064
Taste—45 min.	none	tr. I	I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I
18 hrs.	tr. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I
Odor —45 min.	?	tr. I	tr. I	I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I
18 hrs.	tr. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I

Experiments made to determine if addition of lime would remove iodoform taste

	Col. 1	*Col. 2*	*Col. 3*	*Col. 4*	*Col. 5*	*Col. 6*	*Col. 7*	*Col. 8*	*Col. 9*	*Col. 10*	*Col. 11*
Phenol, p.p.m.	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Cl, p.p.m.	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205
Taste and odor, 45 min.	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I	s. I
Cl added, p.p.m.		0.513									
Lime added, p.p.m.			37	45	52	60	67	75	82	90	97
Taste and odor, 2 hours	s. I	Cl	tr. I	?	?	?	?	?	?	?	?
20 hours	s. I	tr. Cl	s. I	I	I	I	I	I	I	I	I

Note: Column 2. Excess chlorine was applied to the water after the iodoform taste had developed. It will be observed that the iodoform taste was removed and a chlorinous taste resulted.

Column 5. The amount of lime applied (52 p.p.m.) was the theoretical amount necessary for removal of temporary hardness.

Column 11. This sample was filtered through three feet of sand. Filtrate tasted very strongly of iodoform. (Sample was filtered after the experiment had been completed.)

?, Doubtful.
tr., Trace.
s., Strong.
I., Iodoform.
Cl, Chlorinous.

were obtained when treating Lake Ontario water. In other waters, with varying chemical contents, different ranges might be recorded. The extensive nature of the figures makes a summary difficult. Briefly, it may be stated, that applied chlorine in doses up to 0.1 p.p.m. does not produce taste in combination with phenol, when this latter substance is present in quantities up to 0.015 p.p.m. Doubtful tastes may occur when chlorine is added in amounts between 0.135 and 0.150 part with phenol present up to 0.015 p.p.m. The critical dosage range occurs when chlorine is added in amounts between 0.175 and 0.4 p.p.m., with phenol ranging between 0.002 and 0.017 p.p.m. An actual combination of 0.22 part of chlorine and 0.007 part of phenol caused a water which both tasted and smelt badly of iodoform. In most of the experiments the taste, when it had once developed, became steadily worse, and in one instance after ten days was still pronounced. Chlorine applied in doses in excess of 0.65 part per million completely eliminated the iodoform taste, when phenol was present up to 0.017 p.p.m., but a faint chlorinous taste was left. In this series of experiments, involving several hundred tests, two definite points were established, first, that, in the presence of small amounts of phenol, an iodoform taste developed when 0.175 p.p.m. of chlorine was added, and, second, the taste persisted until the amount of applied chlorine reached a dosage of 0.65 p.p.m. Having demonstrated that chlorine in excess would take out the iodoform taste, experiments were made to see if increased doses of phenol would act in a similar manner. Chlorinated water containing 0.2 part of chlorine were treated with phenol in doses ranging between 0.010 and 0.064 p.p.m. The water thus treated was almost undrinkable, both tasting and smelling of iodoform. Before passing to other considerations, it should be stated that work carried out in Toronto confirms Houston's work in England, namely, that excess chlorine will completely remove iodoform taste. Assuming, therefore, that the excess chlorine treatment could be successfully applied to most supplies where tastes and odors occur, the problem would narrow down to one involving the determination of the amount of chlorine necessary and the subsequent removal of excess chlorine. Where aeration is possible de-chlorination would in most cases be unnecessary. This would be dependent, of course, upon the amount of chlorine originally applied and absorbed. Radical changes, such as excess chlorine treatment involves, will necessarily alter certain operating conditions, as filtration and sterilization processes. In connection with these, excess chlorine taste and odor could be removed without affecting the quality of the effluent by chlorination prior to filtration. Filters of any kind have remarkable chlorine absorption powers, due in part to their retention of organic matter. For various reasons engineers do not favor this practice, but the writer sees no reason, particularly where mechanical plants are involved, why chlorine could not be applied to the water after sedimentation and prior to its passage through the filters. This would apply, of course, only at times when the excess chlorine system was in use for relieving taste conditions. At Toronto, chlorination prior to filtration has been found to work efficiently and to give satisfactory results. No attempt has been made to use the excess chlorine treatment, but it will in all probability be tried out this summer. Laboratory experiments have demonstrated, however, that filtration does decrease the iodoform taste, and, if the application of chlorine may be so controlled that this taste is not allowed to develop, there should be no reason why the chlorinous taste could not be removed by application before filtration. The removal of excess chlorine by chemical reagents depends entirely upon local conditions. If the location of plant and the quality of the water are favorable, there is no reason why this system could not be undertaken, if it is borne in mind always that technical supervision is essential. The success of the treatments has been demonstrated by Houston.

Recently, the removal of the iodoform taste by excess lime, has been tried in Toronto. While the experiments are not yet sufficiently advanced, preliminary observations are not favorable. It was found, however, that the taste was reduced, but not eliminated, when using large quantities of lime. The combination of the characteristic taste produced by excess lime in water, together with the iodoform taste, rather masked the true taste. Three separate observers were able to detect the iodoform taste after a twenty hour contact period. Water treated with chlorine, phenol, and lime, and having a doubtful taste, was passed through a rapid sand filter, when a pronounced iodoform taste resulted, thus confirming the opinion previously expressed that lime only masked the iodoform taste. Taste occurring in the treated water at a temperature of 60°F. was less pronounced than at 45°F.

The experiments as conducted by the Milwaukee Sewerage Commission under Hatton and Copeland and described in the 7th Annual

Report of the Commission are of particular interest. Ammonia condensation liquor was found to contain as much as 0.144 per cent of phenol (carbolic acid). In the experiments with ammonia condensation liquor, containing 0.078 per cent of phenol and other taste producing compounds, it was shown that one part of the liquor produced a taste in 40,000 parts of chlorinated Lake Michigan water. The a.c. liquor was added to sewage entering an aeration tank in quantities ranging between 0.8 and 9.1 per cent of the sewage flow. No taste of consequence was delivered in the effluent except on one or two occasions. At such times the taste was so slight that, when the effluent was diluted with lake water, no taste could be noticed in the diluted sample. The conclusions were that, under warm weather conditions, the activated sludge process of sewage purification will remove the carbolic acid taste in sewage, which contained ammonia condensation liquor equal to 2 per cent of the sewage flow. For that reason it is concluded that the sewage disposal plant should protect the water supply from taste produced by ammonia condensation liquors discharged into the sewers. The absence of taste in many cities during the summer months might be linked up also with this condition, as, where industrial wastes are discharged into sewerage systems, marked seasonal biological activity occurs, which may have much to do with taste prevention.

In conclusion, the writer is strongly of the opinion that if industrial wastes are the real cause of taste occurring in chlorinated water, the best and surest remedy would be the prevention of stream pollution. In some states and provinces laws are in existence which, if enforced, would put an end to the discharge of obnoxious wastes into streams from which public water supplies are drawn. It seems only just that the burden should be placed upon the manufacturers. It is hoped that, if the existing laws cannot be enforced, future provision will be made whereby the burden of preventing stream pollution will be placed upon those directly responsible.

Rudolph Thompson, Assistant Chemist of the Toronto Filtration Laboratory, has been closely associated with the writer in the whole of the investigations recently made in connection with the occurrence of taste in chlorinated water.